

Review

A Review on Solar Energy Utilization and Projects: Development in and around the UAE

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Abstract: Demand on the energy sector has increased significantly due to the incredible evolution of the industry and urbanization. Photovoltaic (PV) technology is rapidly evolving to meet the demands of people in the United Arab Emirates (UAE) by generating more electricity. The UAE has demonstrated that it has the world's highest rates of sun exposure, indicating a significant efficiency in solar energy development. This might be a way to cut down on fossil fuel consumption and greenhouse gas emissions even further. In this review, we discuss five major aspects of solar energy utilization and projects within the framework of the UAE starting with (i) recent advances in solar scenario and development trends, (ii) electricity production, consumption, and tariffs, (iii) focus on various key aspects of photovoltaic solar installation projects inside the Dubai, Abu Dhabi emirates and other smaller projects in the UAE, (iv) different solar projects outside the UAE, and (v) the solar energy industry, including trading, assembly, manufacturing, installation, and other activities in the UAE. The review finishes with a summary of problems, current developments, and future outlooks.

Keywords: solar energy resource; seven emirates; electricity production and consumption; energy projects in the UAE; solar energy industry



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1. Introduction

In the UAE, demand on the energy sector has increased significantly because of the incredible evolution in the industry and population growth [1,2]. Figure 1 depicts the progressive rise in the population of the UAE. As a result, energy consumption in the UAE is rapidly expanding to satisfy the needs of a growing population [3]. One of the most pressing concerns of the twenty-first century is averting an energy catastrophe. Consideration of energy sources is so vital because they play a crucial role in addressing the demands of the world and the people of the UAE [4]. The UAE is composed of seven emirates: Dubai, Abu Dhabi, Fujairah, Ajman, Ras Al Khaimah, Umm Al Quwain, and Sharjah. Each emirate has its own set of goals, plans, controls, and regulations in place to help develop itself in the UAE. Accessible energy is insufficient for people for a variety of reasons, including a country's developmental profile, people's economic position, and the nature of the country's technical developments. Renewable energy resources, which rely on natural resources to offer an unending supply of sustainable and non-polluting energy, are a feasible alternative to conventional energy resources, which have grown in prominence in recent centuries as a means of alleviating energy shortages [5–9]. Solar energy may be the greatest alternative for the future globe for several reasons. First, solar energy is the most abundant, inexhaustible, and ecologically beneficial renewable energy source accessible today. Second, the power intercepted by the earth from the

sun is around 1.8×10^{11} MW, which is several orders of magnitude greater than the current rate of total energy use [10]. Third, it has received the most attention in a wide range of engineering and industrial applications, including electricity generation [11], solar refrigeration [12], water desalination [13], domestic space heating [14–16], and solar chimneys [17]. The dispersion and intensity of solar radiation are two critical elements in determining the efficiency of the solar PV sector. These two criteria vary greatly between countries. Furthermore, solar energy gadgets can help develop a country's economy and contribute to a sustainable environment.

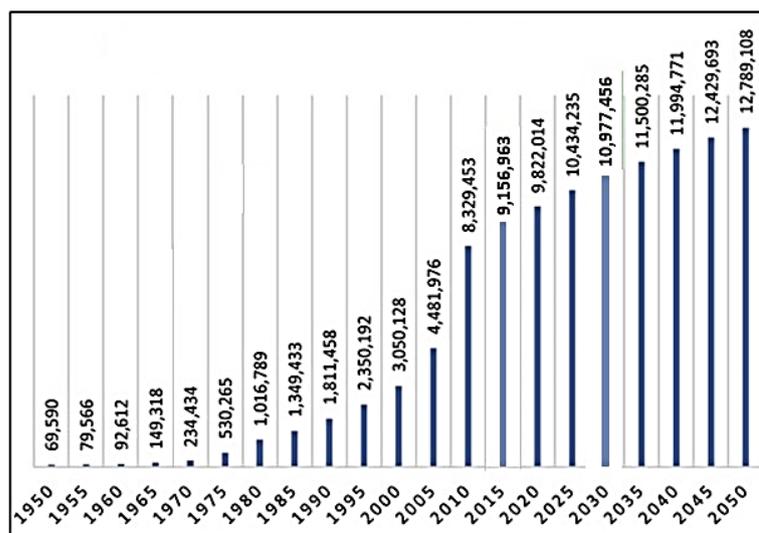


Figure 1. Population status by year in UAE. Reprinted from Ref. [18] with permission from Elsevier (Copyright 2018).

Based on solar photovoltaic technologies, PV technology is the direct conversion of sunlight into electricity with no intervening factors [19]. Photovoltaic devices are designed to be simple and need little maintenance. The main benefit of this system is that it is a stand-alone system with outputs ranging from microwatts to megawatts. As a result, they can be utilized in a wide range of practical applications, including home systems, power sources, distant buildings, water pumps, space vehicles, satellites, communications, reverse osmosis facilities, and even megawatt-scale solar power plants. As a result, with such a diverse range of applications, the demand for PVs grows year after year. Furthermore, solar energy may be turned into electrical energy using a variety of technologies such as PV panels, concentrating photovoltaics (CPT), and concentrating solar thermal power (CSP). Solar PV modules are semiconductor solid-state devices that convert sunlight into direct-current power [20]. Materials used on PV panels are amorphous silicon [21], crystalline silicon [22–26], organic and polymer cells, copper indium selenide (CuInSe), cadmium sulfide (CdS), and cadmium telluride (CdTe) [27–29]. PV systems are made up of numerous components, such as cells, modules, and arrays for generating electricity, and structures for regulating and controlling power, as well as electronic devices, mechanical devices, and electrical connections for improved operating efficiency. Peak kilowatts (kW) is the amount of electrical power supplied by a PV system when it is directly overheated by the sun. Figure 2 shows several materials that have been worked out to increase efficiency in PV devices over the past 5 decades, which reaches 46% in four-junction concentrated solar cells [30,31]. Efficiency is not constant since it is impacted by various external conditions, most notably the intensity of sunshine [32–34].

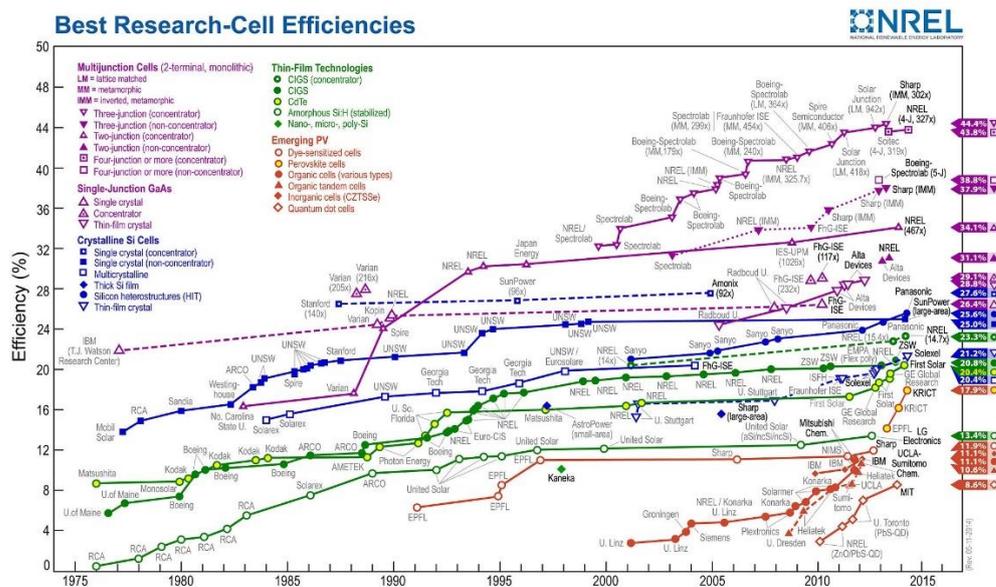


Figure 2. Efficiency of solar cell materials. Source: National Renewable Energy Laboratory. Reprinted with permission from Ref. [35] (CC BY-SA 3.0).

PV panels are often inefficient at absorbing all available energy from sunlight due to design, geographic position, and varying solar intensity throughout the day. In terms of the geographic position of the installation location, the UAE is situated between 22°30" and 26°10" north latitude and 51° to 56°25" east longitude, suggesting that it receives a significant amount of solar energy [36].

Solar tracking system (ST) technologies have been established in recent years to improve the quantity of solar energy captured from the sun. ST is currently classified into two basic varieties based on their movements: single-axis trackers (those that rotate around one-axis) and double-axis trackers (those that spin around two-axes). These devices have lately demonstrated a significant improvement in efficiency on both clear and overcast days, as well as being more environmentally friendly and economically feasible [36]. When compared to fixed traditional PV systems, a single-axis tracker’s energy return commonly approaches 25%, while a double-axis tracker’s energy return often exceeds 40%. Furthermore, while many people still question the efficacy of single-axis trackers, Huang and Sun [37] have shown that they may achieve substantial energy gains, gathering up to 56% more if particular design and control approaches are implemented. When compared to optimally tilted panels, double-axis trackers yielded an energy gain of 20.4% annually [38], whereas incomparable research [39] yielded a yearly energy gain of 43.9%. Meanwhile, while evaluating the performance and economic advantages vs. environmental circumstances of a double axis ST, Enpinar and Cebeci [40] reported a 13.25% improvement in energy gain over an equal size-fixed PV system. Several other researchers have investigated the performance of single and double-axis trackers, showing a 35% energy increase for double-axis trackers over single-axis trackers [35,41,42].

In the past, several other reviews have been published, including Adel Juaidi et al. [3] who deals with energy production, consumption, and greenhouse gas emissions in the UAE. The nuclear and solar energy sources in the UAE were studied by Mehmet F. Orhan et al. [43], in which integrated hydrogen production and thermodynamic analysis were details analyzed based on these sources, and Valerie Evloy and Tesfaldet Gebregziabher [44] investigated future power production options for the UAE, focusing on concentrated solar power (CSP) with thermal energy storage and solar photovoltaic (PV). An overview of greenhouse gas emissions from the energy sector in the UAE was studied by A.N. Khondaker et al. [45]. Steven Griffiths and Robin Mills [46] investigated the possibilities of rooftop solar PV in the growth of the UAE’s energy grid. Zafar Said et al. [18] investigated predictions of the UAE’s renewable energy mix in 2030.

To the best of our knowledge, no detailed evaluations of solar energy resources have been published throughout the United Arab Emirates' seven emirates. The goal of this article is to provide an in-depth examination of current solar energy research and operations in the UAE. As a result, the primary goal of this study is to expand on such basic work by addressing the following issues: 1. an outlook on the UAE, 2. the UAE's energy portfolio, 3. electricity production, consumption, and pricing in the UAE's seven emirates, 4. focus on the many features of PV solar installation projects within the context of the Dubai and Abu Dhabi emirates, UAE, 5. various solar projects outside of the UAE, and 6. the solar energy industry in the UAE. Finally, the review includes a summary, difficulties, current developments, and prospects. Because of higher solar exposure in the UAE, electricity can be produced (rather than coal sources) to meet the demand for population growth while also reducing environmental pollution, particularly CO₂ emissions and other greenhouse gases. This review provides a great opportunity for readers who work in solar energy research in the UAE. The outline of this review is shown in Figure 3.



Figure 3. The layout of this review.

2. An Outlook on the UAE

The UAE has the highest solar exposure rates recorded in the world, as illustrated in Figure 4, showing huge potential for solar development. The UAE is located in the Middle East, in the southwest part of Asia, and is surrounded on four sides by the Arabian Gulf, Saudi Arabia, Qatar, and the Sultanate of Oman [47].

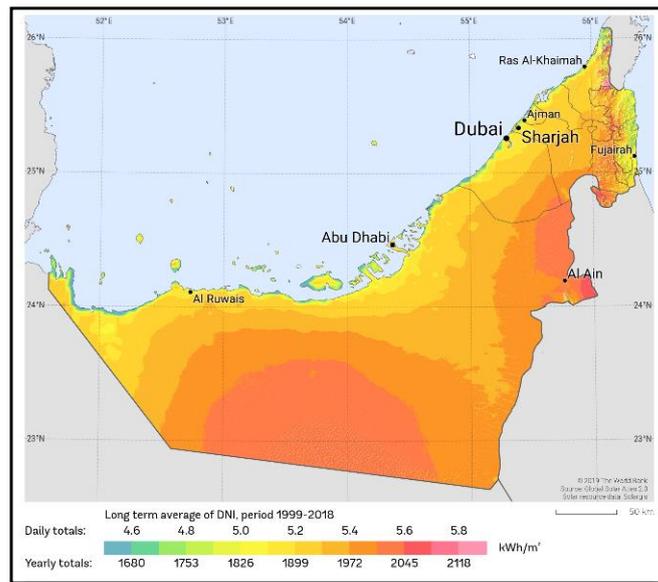


Figure 4. UAE map of Global Horizontal Irradiation (GHI) [48,49].

The entire area of the UAE is 83,600 km², with desert covering 74% and mountains covering 2.6% [47]. As illustrated in Figure 5, the nation contains over 200 islands and a total population of 10 million as of 2021 [50].



Figure 5. Population growth of the seven emirates of the UAE in 2021 based on the last known official population estimate and growth rate [51,52].

The figure below is a map of the UAE’s administrative divisions (Figure 6). Abu Dhabi is the biggest emirate in the UAE, accounting for 84% of landmass territory with a total area of 67,340 km² (13% of the total area of the UAE).

Abu Dhabi has the highest power consumption, owing to its bigger geographic area, followed by Dubai, which has a relatively high energy demand compared to its geographic size. Usually, Dubai has more population, followed by Abu Dhabi, Sharjah, and other emirates in the UAE. As reported in 2021, Dubai has 3.42 million (46%) followed Sharjah, 1.73 million (23.32%), Abu Dhabi, 1.51 million (20.3%), Ajman, 0.39 million (5.36%), Ras Al Khaimah, 0.25 million (3.3%), Fujairah, 0.06 million (0.84%), and Umm Al Quwain, 0.05 million (0.79%). The Sharjah has the second-most population followed by the other emirates. The COVID-19 pandemic has an effect on the people’s lives within the UAE’s emirates.

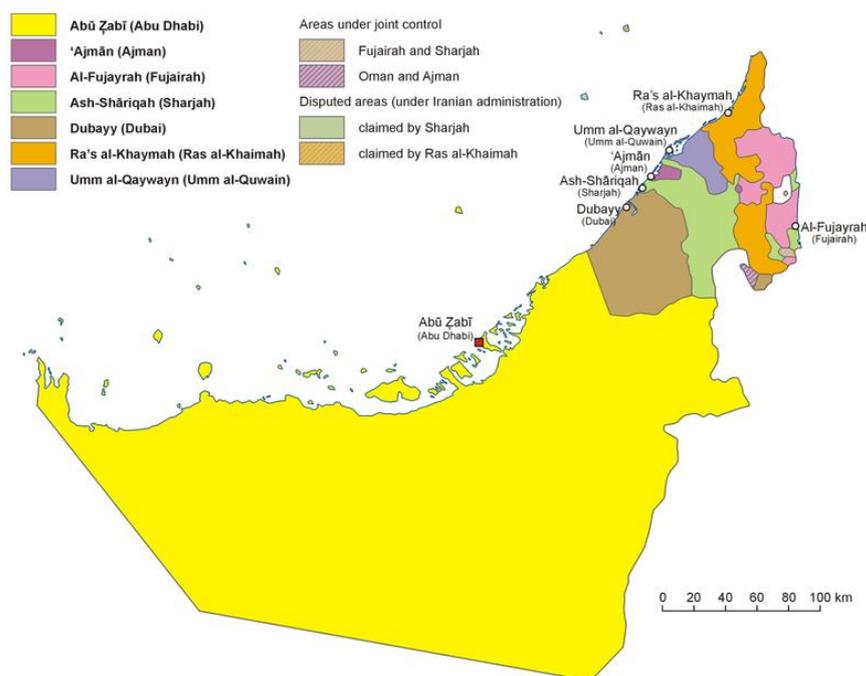


Figure 6. Administrative division map of the UAE. Reprinted from Ref. [18] with permission from Elsevier (Copyright 2018).

3. Energy Scenario and Development Trends in the UAE

The UAE's energy consumption is rapidly growing. Figure 7 depicts that a total electrical energy consumption in GWh of around 131,442 was consumed by the year 2019. This is mainly due to an increase in population growth, demand for water desalination facilities, rapid industrialization, and economic diversification from an oil-based economy. As shown in Figure 1, around 9,541,615 people are living in the country in the year 2018. To meet such energy requirements in the UAE, two primary sources are used: fossil fuels, such as oil and natural gas, as well as alternatives, such as coal and renewable solar power energy [53–55]. The UAE has generated electricity in the amount of 98 TWh. However, 99% and 1% of electricity has been produced from natural gas and oil resources, which are cost-effective but lead to polluting the environment, particularly through CO₂ generation and other greenhouse gases [55]. In the UAE, more than 90% of total greenhouse emissions (GHG) are attributed to the energy sector [56,57]. Figure 8 depicts the total CO₂ emissions from energy use. In 2017, about 267.35 million metric tons of CO₂ have been produced [58]. As a result, this causes several environmental concerns, including global warming and climate change, as well as melting ice and sea-level rising. In Figure 9, it is clear that fossil fuel consumption was reduced to 99.81% in 2014 from 100% in 1971, and it may be further reduced in coming years. As a result, the UAE government is taking many initiatives to expand the usage of renewable energy sources. Figure 10 depicts the referred growth rate of renewable energy capacity in the UAE. In the year 2030 reference scenario, a considerable rise in solar power was observed from solar PV, demonstrating its potential trend toward meeting renewable energy demands [59]. PV technology is continually advancing to generate more electricity to suit the needs of UAE residents. Figure 11 depicts developments in renewable energy in the UAE (installed capacity). The development of innovative technologies, such as evacuated tube collectors, focusing, and traction, resulted in significant growth: 389,572 MW in 2017 from 9191 MW in 2007 [60,61].

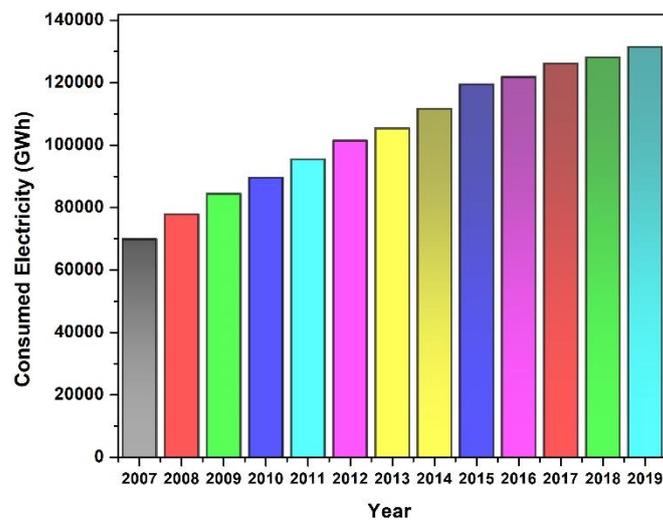


Figure 7. Consumed electricity (GWh) per year in the UAE [62].

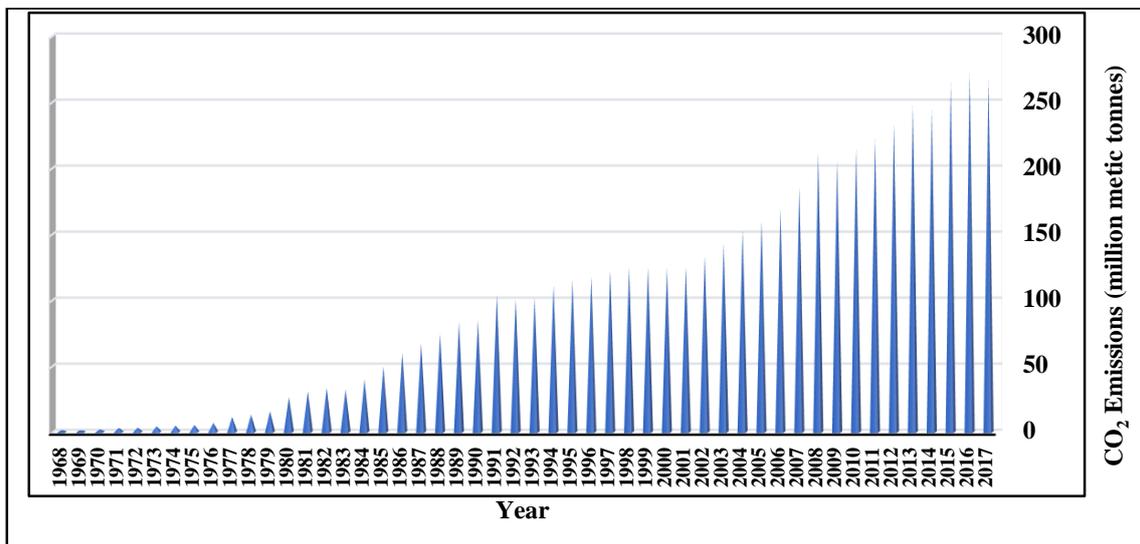


Figure 8. CO₂ emission in the UAE [63].

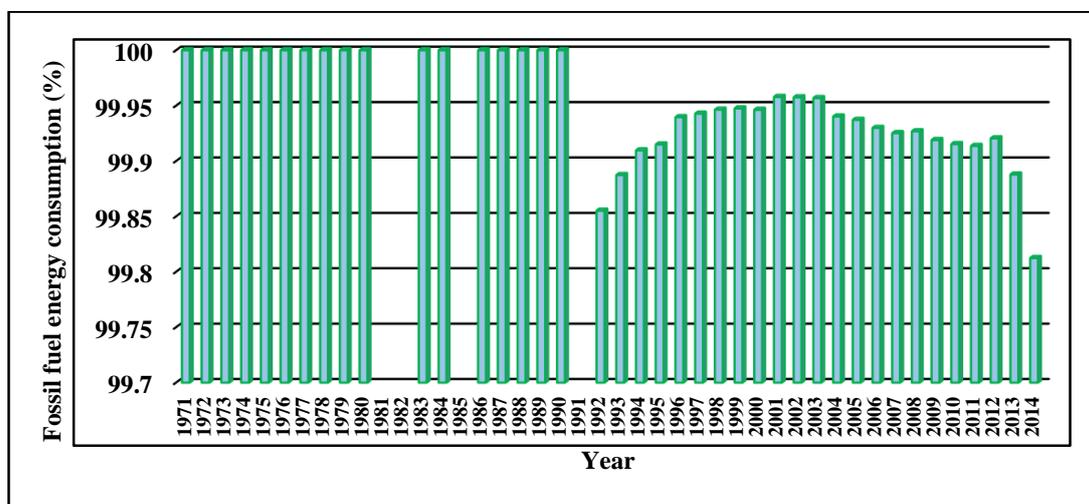


Figure 9. Fossil fuel energy consumption in the UAE [63].

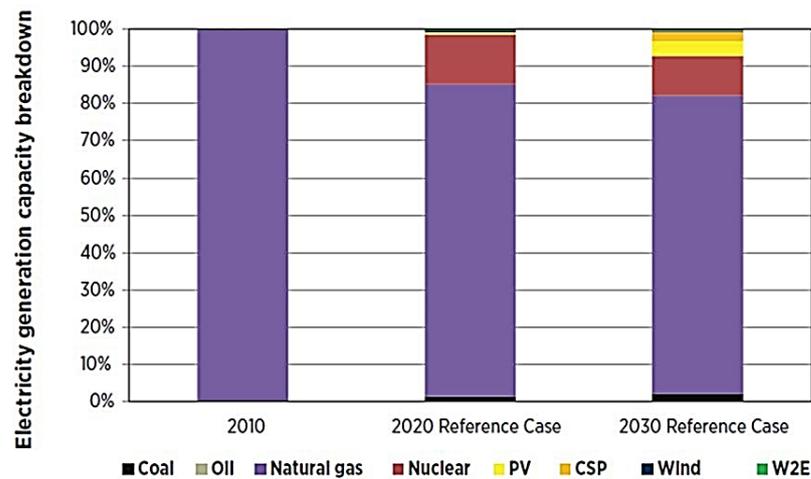


Figure 10. Referred growth rate of renewable energy capacity in the UAE. Reprinted with permission from Ref. [64].

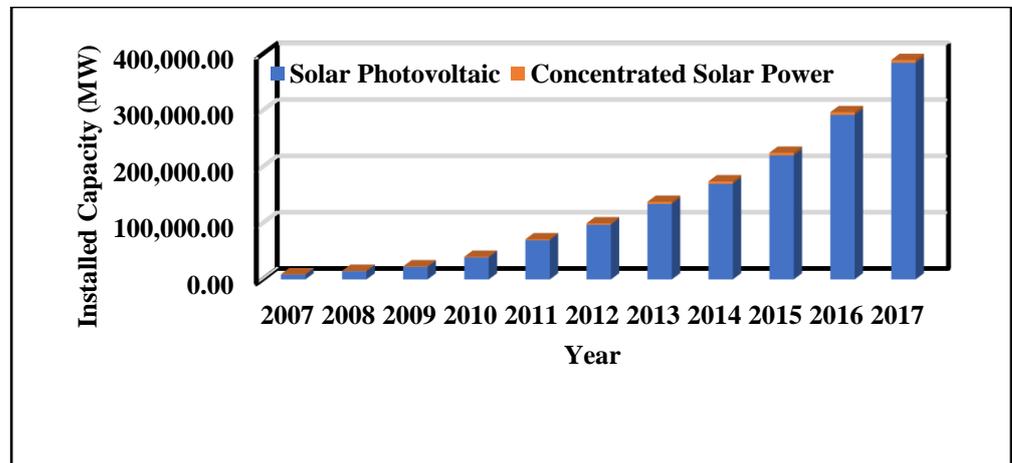


Figure 11. Renewable energy trends in the UAE (installed capacity in MW) [65].

Solar cell production used to be a challenge, owing to its low cost-effectiveness. Many studies have been conducted to minimize such production costs to produce better PV systems [66]. Figure 12 depicts the pricing of solar PV modules in USD per watt from 2010 to 2015. Silicon technology is popular in solar cell design due to its efficiency and suitability. The cost for solar cell manufacturing was reduced from 1.525 USD/Wp in the year 2011 to 0.478 USD/Wp in the year 2013 for thin-film CdS/CdTe; the price of crystalline material (manufactured from Japan) was reduced to 0.697 USD/Wp in the year 2015 from 2.944 USD/Wp in the year 2010; the price of the thin-film a-Si/u-Si module was reduced from 2.127 to 0.503 USD/Wp between 2010–2015; the price of crystalline material (manufactured from Germany) was reduced from 3.129–0.643 USD/Wp between 2010–2015; and the price of crystalline material (sourced from China) was reduced to 0.599 from 2.389 USD/Wp between 2010–2015. All of this is attributable to the PV sector’s implementation of cutting-edge technologies. Furthermore, the solar thermal sector is rapidly expanding. Various collectors are used to capture sunlight in order to create heat with the least amount of loss, which makes them ideal for creating job opportunities in the renewable energy sector. This shows that it is critical to identify the future roles of various energy sources and to explain the actions necessary to transition to a sustainable future energy system.

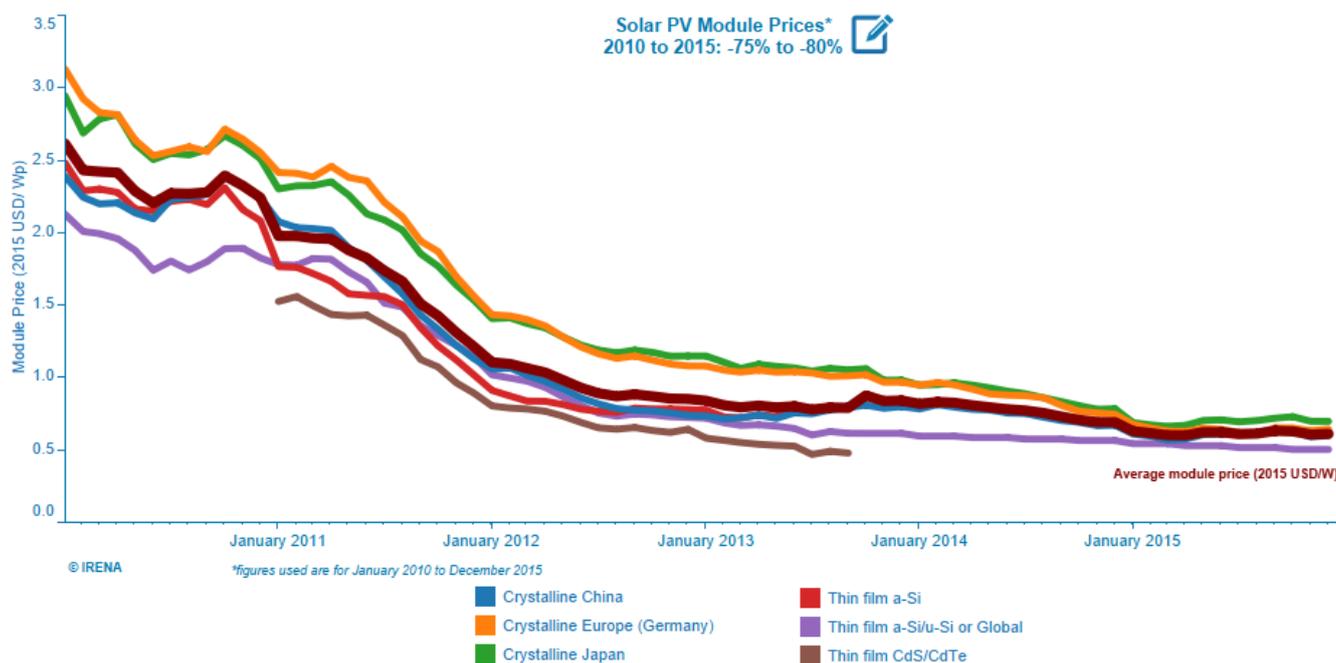


Figure 12. Price history of PV modules. Reprinted with permission from Ref. [67].

4. Electricity Production and Consumption from Seven Emirates of the UAE

Four main utilities have been established to generate electricity in the UAE, namely [68–71]:

1. DoE: Department of Energy (previously known as ADWEA-Abu Dhabi Water and Electricity Authority), under the Emirate of Abu Dhabi;
2. DEWA: Dubai Electricity and Water Authority, under the Emirate of Dubai;
3. SEWGA: Sharjah Electricity Water & Gas Authority, under the Emirate of Sharjah;
4. EWE: Etihad Water and Electricity Authority (previously known as the Federal Electricity and Water Authority, FEWA), under the Emirates of Ajman, Fujairah, Ras Al Khaimah, and Umm Al Quwain.

Each utility has its own rate structure, planning, and investment processes [72–75]. Electricity consumption for each authority from 2013 to 2016 is shown in Figure 13. The DoE authority has the highest consumption of electricity with around 224,372 GWh, i.e., 47.6%, followed by 157,244 GWh for DEWA (33.4%), 44,153 GWh for SEWGA (9.4%), and 45,063 GWh for EWE (9.6%) [76,77]. Figure 14 shows the electricity capacity (MW) of these four authorities from 2007 to 2016. It is clearly shown that electricity capacity increased from 2007 to 2016 due to an increase in demand for electricity. DoE has a 129,056 MW capacity, i.e., 51.8%, followed by 83,817 MW for DEWA (33.7%), 26,451 MW for SEWGA (10.6%), and 9411 MW for EWE (3.8%). Moreover, these four emirates authorities have increased their capacity to 28,761 MW in 2016 from 17,700 MW in 2007. Figure 15 shows the gross generated electricity by each authority from 2007–2016 [78]. Only the DoE and DEWA authorities have increased their gross generated electricity, from 38,592 GWh (2007) to 80,527 GWh (2016) and 26,030 GWh (2007) to 43,091 GWh (2016), respectively, whereas SEWGA and EWE have reduced gross electricity generation from 8968 GWh (2007) to 5684 GWh (2016) and 5171 GWh (2007) to 292.54 GWh (2016), respectively, which is due to less investment in the electricity sector. DoE has a gross generated electricity of 586,099 GWh, i.e., 57.1%, followed by 352,951.95 GWh for DEWA (34.4%), 64,241.86 GWh for SEWGA (6.3%), and 24,405.14 GWh for EWE (2.4%) [79,80]. Figure 16 shows the import–export electricity quantity by country from 2012 to 2016.

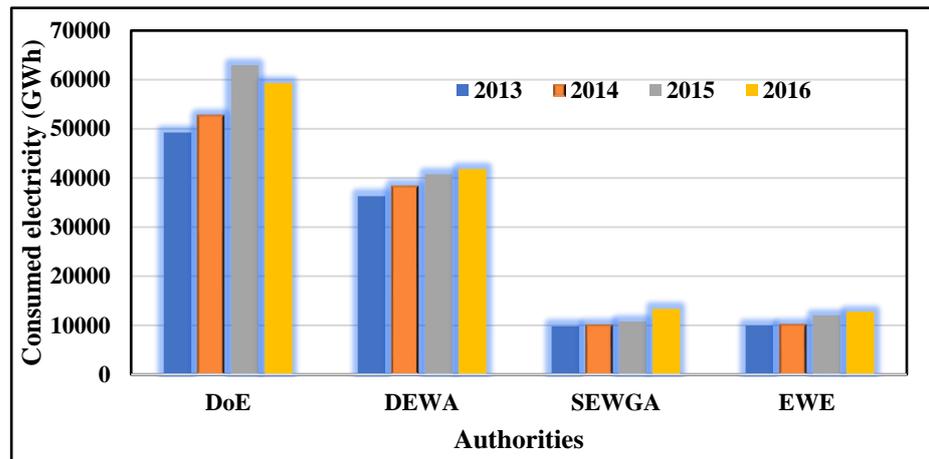


Figure 13. Consumed electricity (GWh) by authority [81].

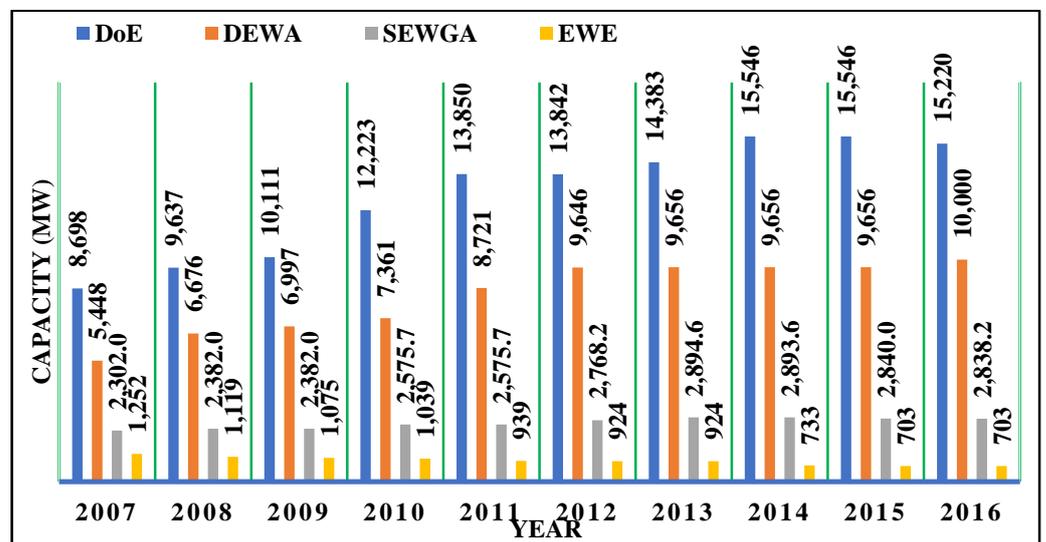


Figure 14. Electricity capacity in DEWA, DoE, SEHA, EWE (MW) [81].

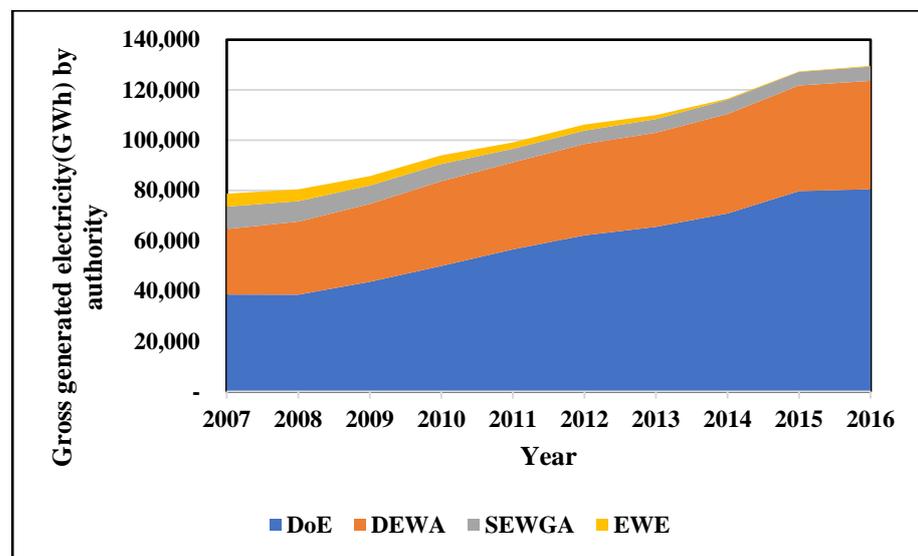


Figure 15. Gross generated electricity (GWh) by authority [81].

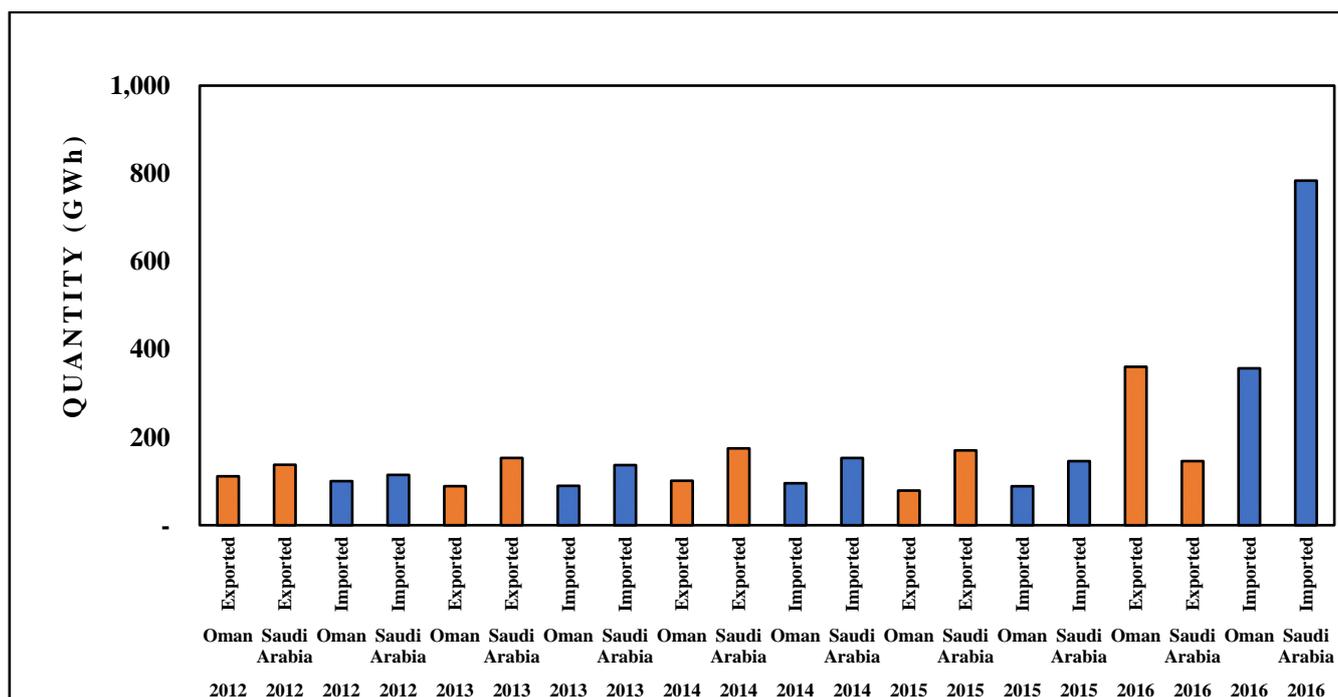


Figure 16. Export and import quantity (GWh) to Oman and Saudi Arabia [81].

Hence, in the recent decade, the UAE’s energy power generation and consumption from these authorities have expanded considerably. This electricity has mostly been produced by natural gas-fired power stations in the UAE, which pollute the environment, particularly in terms of CO₂ emissions and other greenhouse gases. This situation is projected to improve in the next few years. To avoid this, governments, businesses, and the general public must acknowledge that the prioritization of climate change problems as a top priority in economic and social growth processes is inescapable. As a result, the UAE government must encourage a diverse energy mix in which electricity may be generated from all traditional energy sources, including sustainable energy, nuclear, and coal power.

Electricity Tariffs from Authorities

Electricity pricing ranges greatly among the administrations of these four emirates, including within sectors such as residential, commercial, industrial, agriculture, and between UAE residents and expats. For example, in the Abu Dhabi emirate, the rate of electricity in fils/kWh (1 fil = 0.027 USD) increased slightly from 2016 to 2017. For residential customers-expats it is 21–26.8 fils, for residential customers-UAE nationals it is 5.5–6.7 fils, for the agriculture class, including ranches, it is 3–4.5 fils, for fisheries and livestock it is 16–20 fils, and for industrial consumers it is 16–28.6 fils (below 1 MW) [82–84]. In general, the formula below is used to calculate electricity consumption based on the authorities provided below,

$$E = P \times (t/100) \tag{1}$$

where *E* refers to the kilowatt per hour (kWh) or measured joules, *P* refers to power used per unit in watts, and *t* refers to the time over which the power is consumed.

Table 1 represents the DoE electricity tariff by slab rate sector in 2016. It shows that electricity tariffs vary based on sector, nationality, unit type, slab rate, and category. Table 2 lists the electricity tariffs of the DEWA, SEWGA, and EWE authorities’ slab rate sectors in 2016. It shows that electricity tariffs vary concerning authority, sector, nationality, and slab rate.

Table 1. DoE electricity tariff by slab rate sector in 2016 [85].

Sector	Nationality	Unit Type	Slab Rate	Category	Tariff (fils/kWh)
Residential	National	Flat	Less than or equal 30		5
Residential	National	Flat	More than 30		5.50
Residential	National	Villa	Less than or equal 400		5.00
Residential	National	Villa	More than 400		5.50
Residential	Expat	Flat	Less than or equal 20		21.00
Residential	Expat	Flat	More than 20		31.80
Residential	Expat	Villa	Less than or equal 200		21.00
Residential	Expat	Villa	More than 200		31.80
Commercial			Fixed		16.00
Industrial			Load < 1 MW		16.00
Industrial			Load > 1 MW	Out of Peak	16.00
Industrial			Load > 1 MW	During Peak	30.00
Agriculture			Fixed		3.00
Livestock and Fisheries			Fixed		16.00
Governmental			Fixed		29.70

Table 2. Electricity tariffs of DEWA, SEWGA, and EWE authorities' slab rate sector in 2016 [85].

Authority	Sector	Nationality	Slab Rate	Tariff (fils/kWh)
DEWA	Residential	National	2000 to 2001	7.5
	Residential	National	4000 to 2001	9.0
	Residential	National	6000 to 4001	10.5
	Residential	National	6001+	12.5
	Residential	Expat	2000 to 2001	23.0
	Residential	Expat	4000 to 2001	28.0
	Residential	Expat	6000 to 4001	32.0
	Residential	Expat	6001+	38.0
	Commercial		2000 to 2001	23.0
	Commercial		4000 to 2001	28.0
	Commercial		6000 to 4001	32.0
	Commercial		6001+	38.0
	Industrial		10,000 to 10,001	23.0
	Industrial		10,001+	38.0
	Agriculture			
	SEWGA	Governmental		10,000 to 10,001
Governmental			100,001+	38.0
Residential		National	2000 to 2001	7.5
Residential		National	4000 to 2001	7.5
Residential		National	6000 to 4001	7.5
Residential		National	6001+	7.5

Table 2. Cont.

Authority	Sector	Nationality	Slab Rate	Tariff (fils/kWh)
	Residential	Expat	2000 to 2001	30.0
	Residential	Expat	4000 to 2001	33.0
	Residential	Expat	6000 to 4001	37.0
	Residential	Expat	6001+	43.0
	Commercial		2000 to 2001	28.0
	Commercial		4000 to 2001	33.0
	Commercial		6000 to 4001	37.0
	Commercial		6001+	43.0
	Industrial		10,000 to 10,001	44.0
	Industrial		10,001+	44.0
	Agriculture			7.5
	Governmental		10,000 to 10,001	40.0
	Governmental		100,001+	40.0
EWE	Residential	National	2000 to 2001	7.
	Residential	National	4000 to 2001	7.5
	Residential	National	6000 to 4001	7.5
	Residential	National	6001+	7.5
	Residential	Expat	2000 to 2001	28.0
	Residential	Expat	4000 to 2001	33.0
	Residential	Expat	6000 to 4001	37.0
	Residential	Expat	6001+	43.0
	Commercial		2000 to 2001	28.0
	Commercial		4000 to 2001	33.0
	Commercial		6000 to 4001	37.0
	Commercial		6001+	43.0
	Industrial		10,000 to 10,001	44.0
	Industrial		10,001+	44.0
	Agriculture			7.5
	Governmental		10,000 to 10,001	28.0
	Governmental		100,001+	43.0

Power pricing in Dubai and the northern emirates is based on a slab system (i.e., higher rates for higher consumption levels). The minimum consumption category (<2000 kWh/month) for residential and business customers in Dubai is 23 fils/kWh, while the maximum (>6000 kWh/month) is 38 fils per kWh. In some cases, Liquefied Natural Gas (LNG) tax (5%) is also applied. The UAE is an LNG importer. LNG imports in the GCC states began in 2009 as a stopgap measure to help meet seasonal demand peaks, but have since become a more consistent feature of yearly demand. Using the identical usage categories, residential and business prices in the northern emirates begin at 20 fils per kWh and peak at 33 fils per kWh. For industrial customers, the northern emirates pay a fixed rate of 40 fils per kWh; however, Dubai offers two categories (below and above 10,000 kWh/month) at 23 and 38 fils per kWh. In early 2015, the northern emirates' tariffs were raised by 5 fils per kWh. In Sharjah, regardless of consumption, residential users pay 30 fils/kWh and industrial consumers pay 40 fils/kWh. Commercial customers using less than 10,000 kWh/month

are charged 30 fils per kWh, while those using more than 10,000 fils/kWh are charged 35 fils/kWh (Ministry of Energy-UAE, MOENR, 2013).

Electricity pricing is affected by governmental incentive schemes and regulations, domestic economic fuel prices, and local weather. The price of electricity in the UAE varies between emirates as well as between expatriates and citizens. Electricity prices in the UAE have been reformed numerous times. Their impact on the country's citizens has been limited, but they have had a greater impact on expatriates. While the distribution of electricity prices for Dubai and Sharjah is based on monthly consumption slabs, the prices in Abu Dhabi vary depending on housing type (villa or apartment), with the segments based on daily levels of consumption. The emirates of Dubai and Abu Dhabi have relatively high commercial and industrial activity [86–88]. To satisfy demand, DoE also exports power to neighboring emirates [89]. These four organizations work to fulfill a need that is increasing at the same rate as the population. Electricity consumption is related to the high cooling load required to maintain thermal comfort in the UAE [90].

5. Solar Energy Projects in the UAE

In this section of the study, we focused on major and minor solar energy projects in all emirates of the UAE. Then, we covered sponsored solar energy projects outside of the UAE. The main aim of all solar energy projects in the UAE is to reduce CO₂ emissions and promote a greener environment and to provide electricity and cost-competitive tariffs for households.

5.1. Solar Energy Projects in the Dubai Emirate

This section investigates solar energy projects inside the Dubai emirate, UAE. For this, we found that some of the solar projects were already installed elsewhere and are expected to be complete by 2030. In this view, we presented the world's biggest solar park in Dubai, i.e., the Sheikh Mohammed bin Rashid Al Maktoum project, which is compressed into five phases, depending on the electricity capacities that are produced. Then, we covered various rooftop solar projects inside the Dubai emirate, which include Etihad ESCO, Dubai's mountainous Hatta region, the Mall of the Emirates, and the Dubai Solar Schools Program.

5.1.1. Sheikh Mohammed Bin Rashid Al Maktoum Solar Project

As seen in Figure 17, the Sheikh Mohammed bin Rashid Al Maktoum solar project is the world's biggest solar park, with a total area of 77 km² in Seih Al-Dahal, some 50 km² south of Dubai. The project was constructed by the Dubai Electricity and Water Authority (DEWA). It has a planned production capacity of 5000 MW by 2030, with total contributions worth up to AED 50 billion (USD 13.6 bn). When completed, the solar project will save more than 6.5 M tones of CO₂ each year [91]. To offer sustainable energy to Dubai's people and residents, the solar park will employ a variety of PV and CSP technologies. It has an innovation center, testing facilities, a research and development center, and a solar-powered water desalination system. There are five stages of solar energy generation, as illustrated in Table 3.

Hence, these five phases of the Sheikh Mohammed bin Rashid Al Maktoum solar project make them useful and promising in supplying electricity to homes, schools, and public buildings, as well as to the industry/company needs of the project. The plant also reduces CO₂ emissions in the UAE significantly. In addition, it concentrates on the solar thermal power (CSP) and photovoltaic (PV) technologies that are used to convert solar energy into electricity for this project.



Figure 17. Solar projects in the Sheikh Mohammed bin Rashid Al Maktoum Solar Park, Noor 1 Photovoltaic Solar Power Project, Um Al-Zomul off-grid power project, and Shams 1 [92].

Table 3. List of the five phases of the Sheikh Mohammed bin Rashid Al Maktoum solar project with main characteristics.

Phases	Capacity (MW)	Panel Type	Area	Reduction of CO ₂ Emissions/Annually	Main Characteristics
First	13	PV	280 km ²	15,000 tonnes	This phase consists of around 152,000 PV solar panels linked to 13 transformers in inverter buildings. The output is converted to 33 kV and annually generates about 28 million kilowatt-hours (kWh) of electricity.
Second	200	PV	4.5 km ²	214,000 tonnes	Based on Independent Power Producer (IPP) model. This phase installed 2.3 million PV solar panels with a total investment of AED 1.2 billion with a consortium of Saudi Arabia’s ACWA Power and Spain’s TSK.
Third	800	PV	4.48 km ²		Based on the IPP model. This project makes use of 806,992 PV polycrystalline panels. DEWA controls 60% of the enterprise, while the consortium owns the other 40%, with Masdar owning 24% and EDF Energies Nouvelles owning 16%.
Fourth	950	CSP and PV			Largest single-site CSP solar project in the world situated on the IPP model. The project will cost AED 14.2 billion. It is being carried out by a consortium that includes the Silk Road Fund, ACWA Power–Saudi Arabia, and Shanghai Electric–China.
Fifth	900	PV			This phase, starting in Quarter 2 of 2021, will be commissioned in stages.

5.1.2. Rooftop Solar Energy, Dubai

Recently, the Dubai emirate has announced the largest rooftop solar project in the UAE, which includes Etihad ESCO, with a capacity of 60 MW peak that will see photovoltaic (PV) panels installed on 640 villas in Dubai's mountainous Hatta region. DP World is constructing the country's largest distributed plant, with a total capacity of +20 MW peak with 51 rooftops and 4 parking garages. ALEC Energy Company is now constructing a 6.4 MW peak for Nabooda and a 6.5 MW peak rooftop for Emaar on the Dubai Hills, and Alsa Solar Systems has completed a 2 MW peak for the Mall of the Emirates, with four more MW pending in the MAF group in the UAE. Aramex, Pepsi, ABB, and the Al Tayer company have all declared rooftop ambitions as part of the Dubai Solar Schools Program [93–95].

The Sheikh Mohammed bin Rashid Al Maktoum solar project has generated more electricity than other projects. Additionally, the deployment of solar energy plants is impacted by the global market's rising oil prices and lowering solar module prices. Furthermore, it was discovered that processes powered by solar parks have a lesser environmental effect in terms of CO₂ emissions. The rooftop electricity power generation has been used successfully in the residential and commercial sectors, making building-integrated PV an appealing choice for widespread solar energy adoption. PV panels are currently planned to be installed directly on the exteriors of houses in order to save money on construction.

5.2. Solar Energy Projects in the Abu Dhabi Emirate

In this study, we focused on several solar energy projects installed inside the Abu Dhabi emirate, UAE. We investigated the projects in the following order: Solar PV Farm in Masdar City, Shams 1, Noor 1, Um Al Zomul off-grid, Murawah Island, Sweihan, and the Abu Dhabi solar rooftop project [65,96,97]. Each project has a different capacity of electricity that is produced, as illustrated in Figures 17 and 18. The ultimate aim is to reduce CO₂ emissions significantly when solar facilities are erected instead of gas-powered plants.

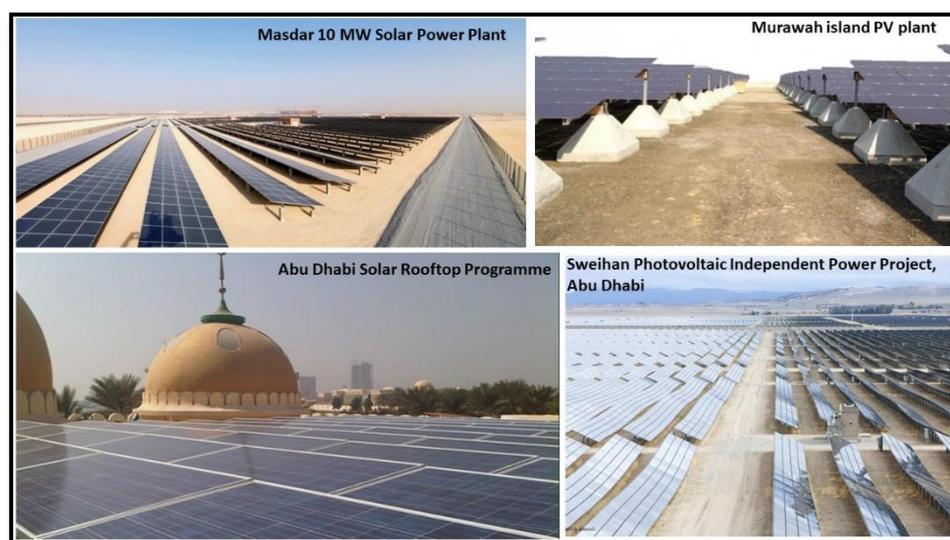


Figure 18. Solar projects in Masdar 10 MW Solar Power Plant, the Murawah Island PV plant, Abu Dhabi solar rooftop program, and the Sweihan Photovoltaic Independent Power Project, Abu Dhabi.

According to this study, when solar facilities are erected instead of gas-powered plants, CO₂ emissions significantly decrease, and PV/CSP may play an important part in satisfying Abu Dhabi's energy needs beyond 2020.

6. Other Small Solar Projects Inside the UAE

Masdar's portfolio includes a variety of minor projects in addition to big projects, such as the Masdar City solar power and Shams 1 facilities. Solar-powered water wells, island grids, lighting, and sustainable agriculture are among them.

Here are some specifics regarding such projects:

1. Al-Ain Diwan lighting efficiency: Replacing lights in Al Ain, UAE;
2. Al Hayl Island, UAE: Fifteen hybrid systems with a peak capacity of 200 kW, powered by a battery, diesel generator, and a reverse osmosis package;
3. Al-Jarnain: A solar power grid with a peak capacity of 750 kW on Al Jarnain Island in the United Arab Emirates;
4. Al Wathba stables: A 120-kW on-grid solar photovoltaic plant;
5. Omran hospital in Ras Al-Khaimah has a rooftop photovoltaic with a 450-kW peak and PV-powered streetlights;
6. Sea Palace: A 200-kW on-grid photovoltaic electricity;
7. Sustainable farm: Al Ain, UAE has an eight-acre sustainable farm;
8. Concentrated PV pilot: Masdar City, UAE, 600-kilowatt peak grid.

As a result, these projects are currently concentrating on additional power generation to meet the rising electricity demand in these areas. They also help transform the UAE's energy mix, leading to decreases in the nation's carbon impact and supplying enough energy to residential houses. Furthermore, with such a large amount of PV energy, the UAE is believed to have the highest potential of any Gulf Cooperation Council member country (GCC).

7. International Solar Projects: Sponsored by the UAE

In this study, we also focused on 16 solar energy projects installed outside of the UAE. The UAE is largely involved in the PV sector, mainly through Abu Dhabi's Masdar Program, by investing in solar projects [98]. Below are a few examples.

7.1. Masdar Special Projects, Egypt

As illustrated in Figure 19a, Masdar has built and installed 7000 off-grid solar household PV systems in houses and commercial buildings in six distant regions, namely Qina, Sohag, Aswan, Matrouh, Al Wadi Al Jadeed, and Luxor. Between December 2015 and April 2016, Masdar installed seven solar-diesel plants totaling 20 MW at 5 MW from Shalateen, 2 MW from Abu Ramad, 6 MW from Marsa Alam, 1 MW from Halayeb, 500 kW from Darb Al Arbaeen, 500 kW from Abu Minqar, and 5 MW from Al Farafra in the governorate of the Red Sea and the Al Wadi Al Jadeed Governorate, Egypt, as shown in Figure 19b,c. This project was financially funded by the Abu Dhabi government, UAE, for rural electrification in Egypt, and it was completed in March 2014. The UAE-Egypt Commission is sponsoring Egypt's New and Renewable Energy Authority (NREA). These four projects, each tailored to the requirements of a unique community, offer solar power to medical clinics/hospitals, mosques, educational institutes/schools, and many houses that previously lacked dependable access to power or were not linked to the national grid.

7.2. Baynouna Solar Plant, Jordan

As illustrated in Figure 19f, this project began as a Power Purchase Agreement (PPA) between Masdar and Jordan's state energy supplier, the National Electric Power Company. This USD 240 million projects will create 563.3 GWh of electricity per year, which is equal to 4% of Jordan's annual energy consumption. Construction is set to commence in the first quarter of 2018, with Masdar serving as the project's primary stakeholder. Jordan will be able to meet its objective of producing 10% of its domestic electricity needs from renewable sources thanks to the 200 MW solar power plant and Masdar's 117 MW Tafila windfarm. Jordan aims to build 1.8 gigatonnes of renewable energy by 2020, and the two projects will account for roughly 18% of that total.



Figure 19. Solar projects in (a–e) Egypt and (f) in Jordan.

7.3. Valle 1 and 2 in Cadiz, Spain

Valle 1 and 2 are two solar facilities in Cadiz, Spain, that employ parabolic trough solar technology as well as molten salt storage. The plants were constructed between late 2009 and 2011, as seen in Figure 19d. Torresol Energy, a joint venture between the Spanish engineering firm Sener (60%) and Masdar, developed the newest parabolic trough technology for both projects (40%).

Here are the other solar projects initiated under Abu Dhabi's Masdar Program:

1. 15 MW Sheikh Zayed Solar Project in Nouakchott, Mauritania: Masdar manufactured roughly 30,000 micromorph solar panels and installed 10,000 solar household PV systems, as shown in Figure 19e;
2. Solar Home Systems, Afghanistan: The Masdar project has built 600 solar household systems in 27 communities near Camp Robinson;
3. LaKaRo 525 kW Solar PV, Fiji: Solar panels were installed in the residential area of Fijian islands, such as Lakeba, Rotuma, and Kadevu;
4. 500 kW Rooftop Solar PV, Tuvalu: Roofs and buildings in Tuvalu under the UAE-PPF (Pacific Partnership Fund) project;
5. Micro-grid connected PV plant in Tonga: Solar photovoltaic power measuring 512 kW has been generated through the UAE-PPF;
6. Solar PV Plant in Honiara, Solomon Islands: A 600 kW solar plant;
7. Solar PV and Water Protection, Kiribati: Solar photovoltaic power measuring 500 kW has been generated through the UAE-PPF;
8. Port Vila 767 kW Solar PV, Vanuatu: One hundred and twelve parking spaces and three solar photovoltaic plants;
9. Solar Water Collection in Majuro, Marshall Islands: A 600 kW PV plant;
10. Solar Penetration and Water Access, Palau: On Peleliu island, a 100 kW PV/150 kW low-load diesel hybrid generation project, on Angaur island, a 100 kW PV/100 kW diesel hybrid plant, and on Koror Island, 1001.7 kW solar home systems;
11. Solar House Systems, Morocco: Delivers 19,438 solar household systems in over 1000 rural communities. Masdar's effort in collaboration with ONEE;
12. Nauru Solar, the Republic of Nauru: A 500 kW solar PV facility;
13. FSM Solar, Pohnpei: A 600 kW solar facility.

As a result, significant solar projects in renewable energy were intended to be built outside of the country to assist its energy demands. Among these projects, the Masdar company (under the Abu Dhabi emirate, UAE) is the renewable energy pioneer and arm of the UAE. To enable such a quick scale-up of solar energy technology, the UAE government must be given the authority to adopt comprehensive, comparative views of energy prices and to act on those views in power-sector regulation and tendering.

8. Limitations and Strategy in the Development of Solar Energy: UAE

By receiving solar radiation in the open atmosphere, PV cells and CSP technologies are both essentially current sources. However, achieving the lowest-cost energy mix with inexpensive PV requires flexible generation assets or low-cost storage to supply electricity demand 24 h a day. Combining CSP with thermal energy storage and/or hydropower, depending on availability, is one way to accomplish this flexibility via renewables. There are many ways to affect the performance of PV and CSP technologies in the development of solar energy in the UAE. First, one of the major disadvantages is that their working temperature increases linearly with irradiation in the desert region. It is a generally known fact that solar cell temperature is directly reliant on the electrical conversion efficiency of a PV module. The excess heat generated by a PV module due to the absorption of incoming solar irradiation is considered an electrical loss towards the overall output of the system and also leads to thermal strains being generated. To address the issue of PV systems overheating, researchers have used active and passive cooling techniques, such as a hybrid solar PV/T system, phase transition materials, enhanced heat exchanger channel design, heat sinks, jet impingement cooling, thermoelectric cooling, and other technologies [99]. CSP technology challenges require land resources and are expensive for installation.

Secondly, shadows from atmospheric dust and particulates from industrial sources can never be avoided in the UAE region. Upon deposition and accumulation onto the surfaces of solar cells, they lead to the formation of darker cells and batteries discharging through the solar panel [100]. The dust is mainly made up of silicon dioxide (SiO_2) followed by calcium oxide (CaO) and other oxides/elements, such as SrO, K_2O , MnO_2 , NiO, SiO_3 , Cr_2O_3 , Al_2O_3 , Fe_2O_3 , TiO_2 , P_2O_3 , MgO, and Cl [101–103]. Gypseous soils, i.e., those that contain gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), are the most common mineral found in the desert environment of the Abu Dhabi emirate [104]. More recently conducting polymers, such as polystyrene, poly dimethyl siloxane–siloxane, polymethyl hydroxy siloxane, polyurethane acrylic colloidal suspension, fluorinated polymers, silane-based polymers, and PANI (Figure 20) are also used to enhance the efficiency of solar cells [105,106]. In addition to dust accumulation, i.e., soiling by cementation, capillary aging, or caking/dust herding, two other crucial characteristics, namely, reflectivity and coating durability, play a significant role in lowering solar energy conversion efficiency in the UAE's desert region. As a result, self-cleaning solar cell panels are just as important as capturing solar energy for optimal use. The outcomes of this study can help researchers, designers, and engineers to analyze and come up with a practical solution for the development of PV and CSP systems.

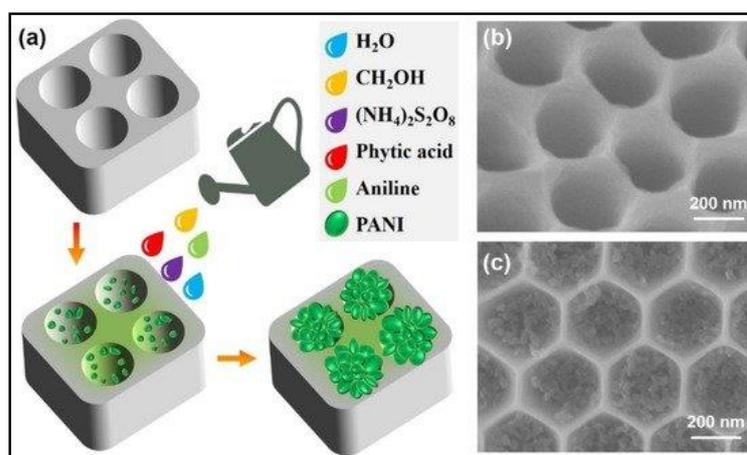


Figure 20. (a) Schematic illustration of the preparation of photothermal materials PANI on a porous anodic aluminum oxide (AAO) membrane. The SEM images of (b) AAO and (c) PANI-AAO. Reprinted with permission from Ref. [107].

9. Solar Energy Industry

According to a 2011 study by Vidican et al. [108] on the solar energy industry in the UAE, there are 77 private companies available in the UAE; among them are 28 in trading, 1 in assembly, 4 in manufacturing PV panels, thermal-collectors, and mirrors, and 44 in installation and other activities, including design, consulting, installation, maintenance, system integration, and turnkey. In the Fujairah emirate (eastern region of the UAE), Microsol International Co, formerly Solon International, is the sole manufacturer of solar cells in Fujairah, UAE, as noted in Table 4. This factory was originally located in India before being relocated to Fujairah, UAE, in 2003. The facility has a total size of 30,000 square feet. The firm can produce 2.5 M solar cells of various sizes. The facility cost USD 3 million to build. It has an annual production capacity of 200 MW. Wet and chemical processing, diffusion, screen printing, silicon nitride coating, and solar-cell testing are among the production procedures handled by the factory's divisions. The product development process includes laser cutting, drawing wafers, diffusion furnaces, wafer preparation, printing and firing lines, and cell testing.

Orders totaling USD 10 million have been placed for shipping to China and Germany. Given the existing demand and supply for solar cells, as well as significant orders in the pipeline, the company has increased the plant's installed capacity from 2.5 M to six million solar cells/year by the first quarter of 2005. In the emirate of Dubai (northern region of the UAE), Maysun Solar FZCO, the first solar module manufacturer, was founded in 2013 in Jabel Ali, Dubai, UAE. This company specializes in the production of solar panels. This plant produced mono and poly modules from 150 W to 370 W—36, 60, 72 cells. It has a nameplate capacity of 40 MW to be expanded to 100 MW in the future. Moreover, its factory capacity is up to 500 MW/year. To provide the highest quality, this plant may use high-quality raw resources from manufacturers around the world, including Iran, Saudi Arabia, Turkey, India, South Africa, Canada, and the EU. Testing, production, raw material acquisition, and quality inspection are all part of the plant production process, including EL and flash tests. Its solar projects were installed in various parts of the UAE, as mentioned in Table 5.

Almaden MENA FZE is one of the UAE's solar panel manufacturing companies, based in the Dubai Silicon Oasis, Dubai, UAE, established in 2017. It is the largest ARC solar double-glass manufacturer in UAE. The plant's capacity was initially set at 150 MW (first phase); however, it may be increased in the future. This plant has a total area of 15,000 m², comprised of 3000 m² manufacturing space and 3000 m² warehousing space. This plant is mainly focused on raw material supply in the solar industry, solar panel manufacturing, and solar project development. This plant produces modules of both mono and polycrystalline solar panels from 325 W to 340 W—40, 50, 60, 72 cells. Its solar projects were installed in various parts of the UAE, for example, swimming pools, rooftop solutions, petrol stations, villas, shading solutions, and agriculture [109].

DuSol Industries is the first solar module manufacturer in Dubai, United Arab Emirates. This plant produces modules of monocrystalline, polycrystalline, thin-film, and flexible types. DuSol, in collaboration with Japanese and German equipment manufacturers, has a 50 MW annual capacity automated line for off-grid and on-grid modules. DuSol manufactures all modules, including off-grid modules, in an automated line with little human participation. This ensures that the modules are of the greatest quality and are of constant quality. This line is unique in that it was designed expressly to generate different-sized modules for off-grid development, including 40–150 Wp, as well as developing high-frequency panels of 240–260 Wp, utilizing 60 polycrystalline solar cells for grid markets [110].

'Enviromena' is the largest solar panel installer company in the UAE in terms of capacity, which is installed in the Dubai World Trade Center, the Masdar Solar PV plant, remote islands, Mamoura parking, the Al Bateen school, the Sheik Zayed Learning Center, Masdar SAF II, the Formula 1–Etihad Airways Grand Prix, and the Abu Dhabi Distribution Company (ADDC) parking and private stables. The Masdar Institute for Science and Tech-

nology is the premier academic institution focusing on renewable energy and sustainability in terms of research and development activities to assist the solar sector, followed by United Arab Emirates University, renewable energy center, and Ajman University, Ajman. Several additional UAE institutes are also conducting research and development activities, sustainable environmental evaluations in different UAE buildings, and solar–hydrogen energy consumption. Renewable energy conferences and workshops (such as Solar Decathlon Middle East) are also held at these universities [111].

In this regard, we note that the UAE has a desert covering 74% of its landmass, i.e., a lot of sand. A detailed geological and chemical analysis of sand from several locations indicates that it has a high SiO₂ concentration under certain areas, which may make it appropriate for the production of silicon-based solar cells. [112,113].

Table 4. List of solar energy projects in Abu Dhabi emirate with main characteristics.

Solar Projects in Abu Dhabi	Capacity	Panel Type	Area	Reduction of CO ₂ Emissions/Annually	Main Characteristics
Solar PV Farm-Masdar City	10 MW	PV	220 km ²	15,000 tonnes	This facility generates 17,500 MWh of renewable power/year. Suntech and First Solar Company use a total of 87,777 polycrystalline (silicon) and 69,048 thin-film modules (CdTe).
Shams 1 plant	100 MW	CSP	2.5 km ²	175,000 tonnes	The world's first and biggest operational CSP plant in North Africa and the Middle East. The project will cost USD 600 million. It is the first CSP plant to be recognized by the United Nations as a Clean Development Mechanism (CDM) project. This project also incorporates a dry-cooling system.
Noor 1 solar plant	100 MW	PV			This plant is located in Al Ain, Abu Dhabi. The first will consist of around 50 MW of crystalline PV modules, while the second will consist of approximately 50 MW thin-film modules east of Al Ain city, with an annual output projection of 170 GWh.
Um Al Zomul off-grid PV plant	100 kW	PV		130 tonnes	The desert off-grid installation plant. This plant's solar energy penetration is based on 100% of the farm's power demand.
Murawah Island	500 kW	PV		710 tonnes	On Murawah Island, Masdar built a grid-connected solar PV facility off the coastline of the UAE.
Abu Dhabi-Rooftop solar program	2.3 MW	PV		3220 tonnes	Installed in 11 municipality engineering houses. Eleven rooftop systems were installed due to this program. The initiative is intended to encourage private individuals, businesses, and other entities to install solar panels.
Sweihan independent power project	1177 MW	PV	780-hectare	7 million tonnes	Based on the IPP model. The project's anticipated investment is USD 870 million. The project is being carried out by the DoE in collaboration with the Japanese firm Marubeni and the Chinese manufacturer JinkoSolar. JinkoSolar will supply high-efficiency monocrystalline PV modules for the solar power plant. DoE owns 60% of the joint venture, while Marubeni and JinkoSolar share the remaining 40%.

Table 5. List of major solar energy industries in the UAE's seven emirates.

Sl. No.	Emirates	The Major Solar Energy Companies in UAE
1	Fujairah	Micro-sol International Co.,
2	Dubai	Maysun Solar FZCO
3	Dubai	Almaden MENA FZE
4	Dubai	DuSol
5	Abu Dhabi	Enviromena

10. Conclusions

10.1. Perspective and Outcomes

This review paper aimed to examine recent advances in solar scenarios and development trends within the framework of seven emirates in the UAE. In this regard, the UAE has been a pioneer in renewable energy production, particularly solar, within the GCC countries. According to the present work, the solar sources available for the UAE include photovoltaic, concentrated solar power (CSP), etc. Using these available resources, the four main authorities have generated electricity production and consumption in the UAE. However, electricity tariffs are varied corresponding to residential, commercial, industrial, and agriculture sectors. The UAE government also sponsors various solar projects outside of the UAE. Finally, this review paper deals with various private solar companies, including those concerned with the trading, assembly, manufacturing of PV panels thermal collectors and mirrors, installation, and other activities available inside the UAE. These solar companies can be used for present or future solar projects in the UAE, helping to increase solar power capacity and to promote a better environment. The UAE is particularly interested in adopting and implementing such RE technologies because of their main advantages, such as the vital role of solar resources in lowering carbon dioxide and other pollutants that contribute to global warming.

10.2. Applications

As a result, the UAE has an abundance of solar energy; passive and active solar energy utilization might be a technique for lowering fossil energy consumption and CO₂ emissions. It is also critical to identify the future responsibilities for the generation of power and to explain the actions necessary for transition to a future sustainable energy system. These have been demonstrated to be policies that are required for the UAE to open the sustainable energy sector and to begin development within the energy sector. It will promote long-term, medium-term, and short-term economic development, and reductions in carbon dioxide emissions will effectively protect the global environment. This may also lead to ecologically friendly electricity growth in the UAE.

10.3. Challenges

PV technology is rapidly evolving to generate more power to meet the requirements of people in the UAE. The UAE government has made numerous measures to expand the usage of renewable sources, including solar, and power has been marked for PV in the year 2030. Nonetheless, many challenges face solar energy growth in the UAE. These include challenges with standby capacity, land usage, and storage inside the emirates. Furthermore, there is a lack of consistency in solar radiation, as well as issues with dust and sand collection on PV panels. Even though sophisticated automation and remote monitoring are required due to the magnitude of PV system implementation, obstacles and opportunities still exist. These monitoring systems, in particular, can reliably indicate when a PV system is not performing to its full potential, but they rarely provide precise actionable information that a solar system owner can take to improve solar performance. There is also a need for more manufacturer companies in all the emirates in the UAE. As a result, there is a need for local content with regard to the research and development of

materials, technology, and applications. Another major task is to raise awareness, share expertise through seminars/workshops, and provide scientific guidance to the UAE's colleges/universities and research institutions. There is a need to alter curricula in engineering programs to incorporate lessons on solar energy resources. Furthermore, the solar-thermal sector is rapidly expanding. Various solar collectors are used to capture sunlight and convert it into heat with the least amount of loss, making them excellent for producing jobs in the renewable energy industry. As a result, the UAE government must encourage a diverse energy mix in which electricity may be generated from all traditional energy sources, including sustainable energy, nuclear, and coal power.

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Acronyms

ADDC	Abu Dhabi Distribution Company
ADFD	Abu Dhabi Fund for Development
ADWEA	Abu Dhabi Water and Electricity Authority
CDM	Clean Development Mechanism
CSP	Concentrated solar power
CVT	Concentrating photovoltaics
DoE	Department of Energy
DEWA	Dubai Electricity and Water Authority
EWE	Etihad Water and Electricity Authority
FEWA	Federal Electricity and Water Authority
GHI	Global Horizontal Irradiation
GHG	Greenhouse Gas Emissions
IPP	Independent Power Producer
MOENR	Ministry of Energy
NREA	New and Renewable Energy Authority
ONEE	Office National de L'electricite et de L'eau Potable
PV	Photovoltaic
PPA	Power Purchase Agreement
RFQ	Request for Qualification
SEWGA	Sharjah Electricity, Water and Gas Authority
SOMELEC	Societe Mauritanienne del Electricite
SHS	Solar Home Systems
ST	Solar Tracking System
UAE	United Arab Emirates

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